

# Opportunities and challenges of sustainable agricultural development in China

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This paper introduces the concepts and aims of sustainable agriculture in China. Sustainable agricultural development comprises sustainability of agricultural production, sustainability of the rural economy, ecological and environmental sustainability within agricultural systems and sustainability of rural society. China's prime aim is to ensure current and future food security. Based on projections of China's population, its economy, societal factors and agricultural resources and inputs between 2000 and 2050, total grain supply and demand has been predicted and the state of food security analysed. Total and *per capita* demand for grain will increase continuously. Total demand will reach 648 Mt in 2020 and 700 Mt in 2050, while total grain yield of cultivated land will reach 470 Mt in 2010, 585 Mt in 2030 and 656 Mt in 2050. The *per capita* grain production will be around 360 kg in the period 2000–2030 and reach 470 kg in 2050. When productivities of cultivated land and other agricultural resources are all taken into consideration, China's food self-sufficiency ratio will increase from 94.4% in 2000 to 101.3% in 2030, suggesting that China will meet its future demand for food and need for food security. Despite this positive assessment, the country's sustainable agricultural development has encountered many obstacles. These include: agricultural water-use shortage; cultivated land loss; inappropriate usage of fertilizers and pesticides, and environmental degradation.

**Keywords:** China; agriculture; sustainable development; food security; strategy

## 1. CONCEPT AND CONTENT OF SUSTAINABLE AGRICULTURAL DEVELOPMENT IN CHINA

Agriculture is essential to human survival and societal development. With worldwide human population growth and economic development, increasing demand for agricultural products has placed substantial pressures on agriculture and natural resources; this in turn has caused environmental pollution and ecological degradation. Agricultural sustainability has become a critical problem that is central to the sustainable development of complex socio-economic–natural systems.

In 1991, the concept of sustainable agriculture and rural development was put forward for the first time at the Conference on Agriculture and the Environment in The Netherlands, held by the Food and Agriculture Organization (FAO) of the United Nations at Herto-genbosch (den Bosch). Its basic principles are to maintain a sufficiency of land for agriculture, to guarantee food security, to improve current living standards, to safeguard the development of future generations and to establish harmonious mechanisms for agriculture and economic development that ensure a prosperous rural society (Schaller 1993). Its general goals are to (i) increase grain yield, ensure food security and eliminate famine, (ii) increase peasants' income, eliminate poverty and stimulate comprehensive agricultural development, and (iii) use and protect natural

resources and the agricultural environment while improving the natural environment for present and future generations.

With 22% of the global population but less than 7% of the global cultivated land, China is confronted with challenges in agricultural development (Smil 1995; Brown & Halweil 1998; Liu & Lu 2001). The recent achievements in increasing grain yield have been realized with high costs to natural resources and environment. This presents a new challenge for China's sustainable agriculture. At present, the concepts and principles of sustainable agricultural development have been included and expressed in a national sustainable development strategy (e.g. China's Agenda 21) and the plan for national economic and social development. The essential goals of China's sustainable agricultural development, widely accepted in China at present, are food security, employment, natural resource conservation and environmental protection. The main components can be generalized as sustainability of the agricultural production, the rural economy, the agroecosystems and the rural society.

Because the primary function of agriculture is to provide food for human beings, it is reasonable that the prime aim of sustainable agricultural development is to secure enough food for present and future generations. In recent decades, demands for food quantity and quality have been increased sharply in China due to the improvement of people's living standards and continuous economic growth. The potential for increased agricultural production is constrained mainly by the extreme shortage of water and cultivated land

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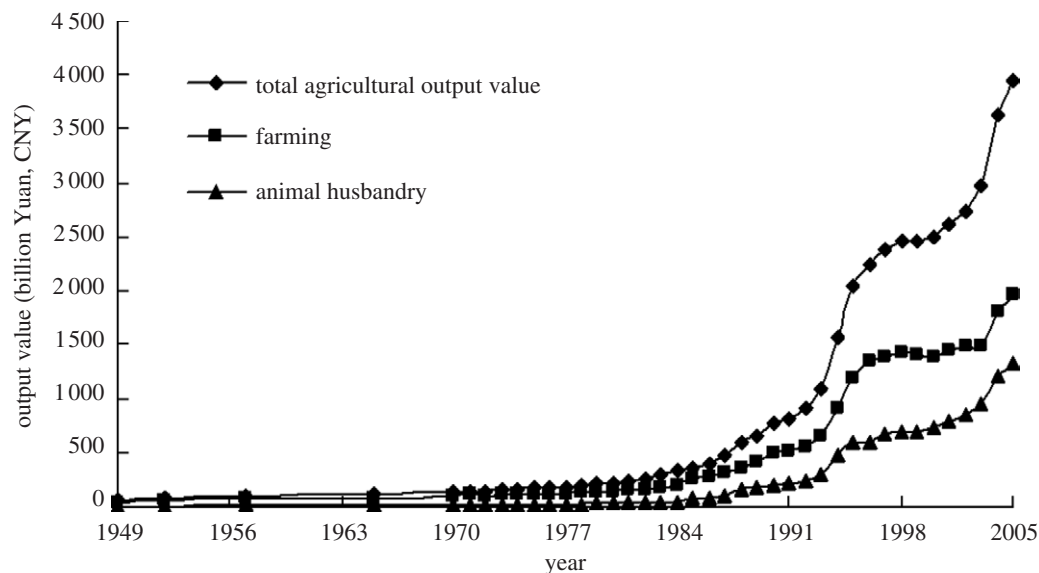


Figure 1. Incremental growth in output value of China's agriculture, 1949–2005. Total agricultural output value combines output from farming, animal husbandry, forestry and fishery.

resources, low productivity, inefficient agricultural policy and management systems and soil degradation. Thus, the issue of greatest concern in China's sustainable agricultural development at present is whether agricultural production can ensure China's food security for the future.

Closely aligned with the aims of sustainable agricultural development in China, we predicted China's food demand and supply and analysed China's food security between 2000 and 2050. The results are provided in this paper. We then go on to discuss other problems regarding sustainable agricultural development in China. The reason why we select the period of 2000–2050 as our time frame for prediction is that China's population, society and economy will undergo a major transition in the next four to five decades. According to China's economic development strategy, the country's economy will continue to develop rapidly to achieve the stated goal of 'reaching the level of medium-developed country'. Accordingly, urbanization will continue and people's living standards will be improved. Even though the curve of China's population will have a turning point around 2030, China's agriculture and food security will still be confronted with great potential problems and challenges in the first half of the 21st century. By 2050, China's economic and social development will slow at the same time as the population will begin to decline with the associated pressure on China's agriculture and food security gradually being relieved.

## 2. A REVIEW OF CHINA'S AGRICULTURAL DEVELOPMENT

Agriculture has always been the basis of China's national economy. Since the establishment of the People's Republic of China in 1949, agricultural development has been accelerated. According to data from China's State Statistical Bureau (CSSB 1985, 1996, 2006), the total production of cereal crops has increased over threefold from 1949 to 2005, with an annual growth rate of 2.63%. The average *per capita* cereal production

in 2005 was 371 kg while in 1998 it had reached 412.4 kg which was the highest this decade and twofold that in 1949.

The data at constant price show that from 1949 to 1957, the total agricultural output value had an annual increment of only 8.9%. In the period 1958–1962, the implementation of the 'Great Leap Forward' damaged China's agricultural development and the increment of output value was low or even negative. From 1963 to 1965, with the end of the Great Leap Forward, agricultural production began to be restored and the annual increment for China's total agricultural output value reached approximately 11%. During the period 1966–1976, the annual increment fell to only 3.3% due to the influence of the 'Cultural Revolution'. When the Cultural Revolution ended in 1976, reform of agricultural economic structures started in 1978. China's agriculture stepped into a period of recovery growth, and the annual increment was 9.4% during 1978–1984. After the recovery period, China's agriculture underwent steady development with an annual increment of 4.1%.

Arable farming and animal husbandry were the two main components of total agricultural activities. From 1949 to 1990, the outputs of arable farming and animal husbandry accounted for more than 90% of the total agricultural output value; this percentage dropped to 83.5% in 2005. The ratio of arable farming output value to the total agricultural output value decreased from 82.5% in 1949 to 49.7% in 2005, while the ratio of animal husbandry output value to the total agricultural output value increased from 12.4% in 1949 to 33.75% in 2005. (figure 1) This indicated that grain still dominated China's total agricultural output but 'multi-management' agriculture was on the increase with the contributions from animal husbandry, forestry and fishery.

The development of China's agriculture was associated with the advances in agricultural science and technology. From 1979 to 2003, more than 40 000 agricultural science and technology inventions were confirmed in China (Niu 2004). The percentage

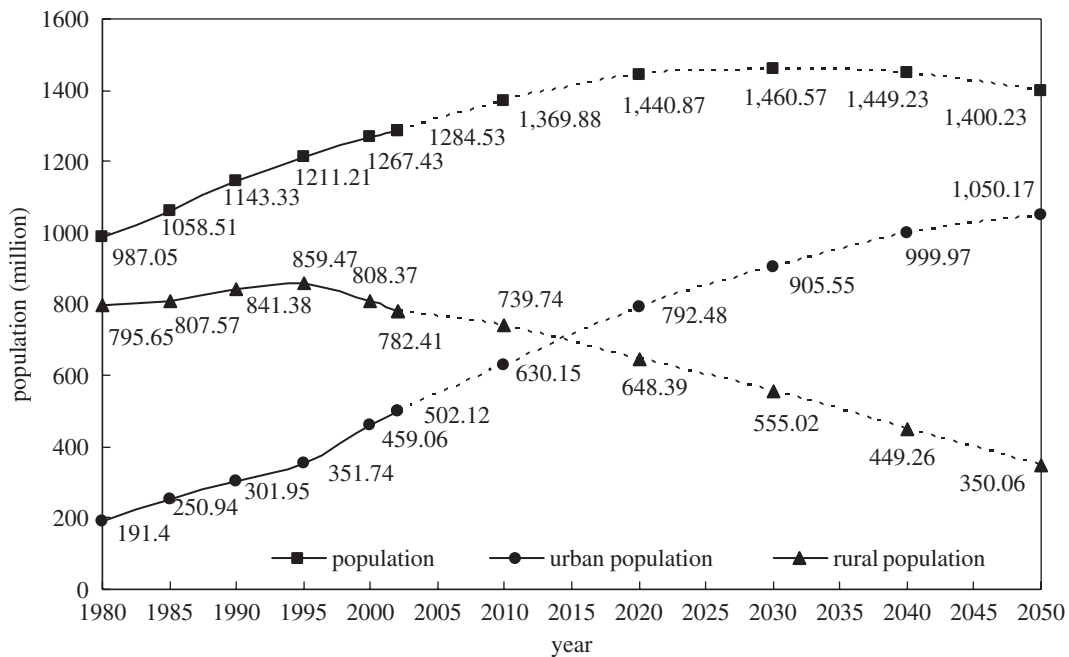


Figure 2. Total, rural and urban population of China, 1980–2050 (from Yan *et al.* (2006).)

contribution of agricultural science and technology to the advancement of agriculture was estimated to be only approximately 20% during 1953–1957 but up to 2000, this percentage contribution rose to approximately 45%. The corresponding percentage contributions of science and technology to increased outputs from arable farming, animal husbandry and fisheries were 42.4, 43.0 and 45.0%, respectively (Niu 2004).

Along with developments in agriculture, other aspects of China's rural economy have also developed well. As an important part of the rural economy, township enterprises have played an increasingly more important role. Facing the increasing competition at home and abroad, township enterprises, driven by reforms, have maintained healthy growth. In 2002, there were over 21.32 million township enterprises in China, which employed 132.88 million people and generated tax revenue of more than CNY 278 billion (Editorial committee of agriculture yearbook of China 2003).

In parallel to these agricultural developments, peoples' food consumption patterns and variety have also been improved, especially since 1978. Between 1978 and 2000, the average *per capita* meat consumption increased from 8.18 to 25.3 kg, egg consumption from 1.67 to 11.8 kg, aquatic products from 3.3 to 11.7 kg and milk from 1.0 to 5.5 kg; however, vegetable consumption decreased from 140 to 110 kg. In summary, China's agriculture has developed tremendously in the recent decades; this has not only met the essential food demands of 1.3 billion people and improved people's living standards but also made a significant contribution to world's food security and sustainable development.

Although much has been achieved in agriculture, China's sustainable agricultural development is faced with serious problems and obstacles, including: a huge human population; scarcity of agricultural resources; environmental pollution and degradation; underdevelopment of rural society and the rural economy; slow

advancement and application of modern agricultural science and technology; and low-efficiency management mechanisms.

The Chinese government is making great efforts to solve these problems. These include strictly protecting cultivated land and the environment; improving resource use efficiency; promoting advancement of agricultural science and technology; developing ecological agriculture; and adhering to long-term population control (*China's Agenda 21* 1994). These efforts and actions will undoubtedly benefit China's agricultural sustainability.

### 3. PREDICTING CHINA'S POPULATION, ECONOMY AND SOCIETAL COMPOSITION IN 2000–2050

Zhao (2003, unpublished report) and Yan *et al.* (2006) have documented predictions about changes in China's human population, socio-economic factors and cultivated land for the period 2000–2050. These predictions provide the foundation and background for the prediction of food demand and production capacity.

From 1980 to 2002, China's total population grew 30.1% per annum, from 987.05 million to 1.28 billion, while the rural population decreased 1.7% per annum, from 795.65 to 782.41 million (CSSB 2006).

These predictions show that China's total population will still be growing (with a decreasing increment) in the coming two or three decades; by 2030, China's population will reach its peak (1.46 billion); after the peak, the total population will gradually decrease to approximately 1.40 billion in 2050. The rural population will decrease more dramatically than the total population from 555 million in 2030 to approximately 350 million in 2050. The magnitudes of the projected total, rural and urban population in China are listed in figure 2. The actual data from 1980 to 2002 are illustrated in the figure along with the predicted data for 2010–2050.

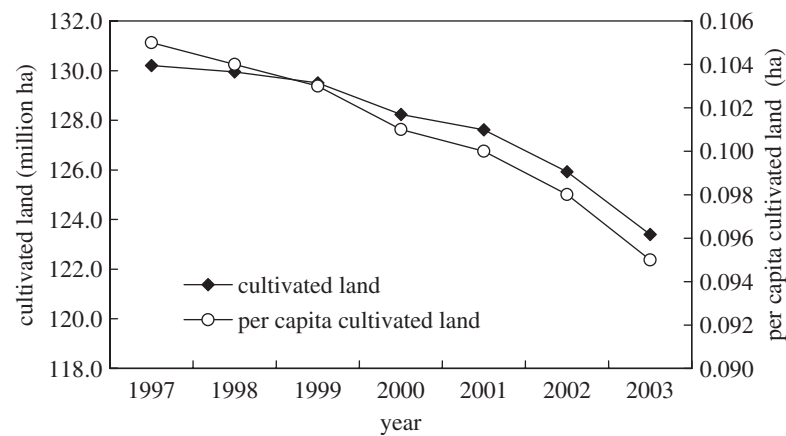


Figure 3. Total and *per capita* cultivated land in China, 1997–2003.

Table 1. Prediction of China's population, economy and society in 2000–2050.

year		2000	2010	2020	2030	2040	2050
population	total (million)	1282.05	1369.88	1440.87	1460.57	1449.23	1400.23
	urban population (million)	459.06	630.15	792.48	905.55	999.97	1050.17
	rural population (million)	808.37	739.74	648.39	555.02	449.26	350.06
society	urbanization level (%)	36.22	46.00	55.00	62.00	69.00	75.00
	GDP (US\$ billion, 2000 price)	1080.0	1934.1	3463.7	5127.1	7589.4	11234.2
economy	GDP <i>per capita</i> (US\$, 2000 price)	842	1412	2404	3510	5237	8024

In 1978, China began economic reform and 'opening-up' in order to achieve the goal of industrialization and urbanization. From 1980 to 1995, China's urbanization level increased from 19.4 to 29.0% (0.64% annually). After 1995, with the effect of China's rapid growth of its industrial economy, the rural population began to decline despite the continued increase in the total population. It can be concluded from the data in [table 1](#) that, in the coming decades, the extent of China's urbanization will be driven by the rapid industrializing of the Chinese economy and will reach 55% in 2020. After 2020, the annual increase of urbanization ratio will be 0.6–0.7 percentage points and by 2050, the level of urbanization in China is predicted to be approximately 75%.

#### 4. STATUS OF CHINA'S CULTIVATED LAND AND FUTURE PREDICTIONS

##### (a) *Status and changes of cultivated land during 1996–2003*

China's land use classification system is different from that used by FAO. Cultivated land is defined under China's system as land that includes: (i) land ploughed constantly for growing crops and under cultivation, (ii) land newly cultivated in the current year, (iii) farmland left without cultivation for less than 3 years and fallowed in the current year, (iv) land in a rotation between grass and crops, (v) farmland with tree plantations (fruit, mulberry and others), and (vi) cultivated sea and lake shores. Ditches, roads and ridges between cultivated fields that are less than 1 m wide in the south or less than 2 m wide in the north are all included as 'cultivated land', while the land used for mulberry fields, tea plantations orchards, nurseries of young plants, forests, reed banks, natural and man-made grassland and all other land are not included in

cultivated land. The area of cultivated land is determined independently of the times or rotations of cropping within a year ([CSSB 2006](#)).

The first national land investigation in 1996 demonstrated that the total area of China's cultivated land was 130.039 Mha, and the *per capita* area was just 0.106 ha; this is only 40% of the world average ([CSLAB 1996](#); [Liu 2000](#); [Lin & Hob 2003](#)). Furthermore, 79% of total cultivated land was medium or low-yielding land and 40% of China's cultivated land was irrigated. An ecological suitability evaluation indicated that only 6.61 Mha (0.70% of the total Chinese territory) could be reclaimed ([Chen 2001](#)). It is therefore almost impossible for China to compensate for loss of cultivatable land by reclamation.

China's cultivated land has declined at an alarming rate from 130.092 to 123.392 Mha during the period 1996–2003 ([figure 3](#); [CSLAB 2000–2003](#)). The loss in cultivated land during 1986–1995 was due to structural adjustments (62% of the total loss), construction (21% of the total loss) and natural hazards (17% of the total loss; [Yan \*et al.\* 2006](#)). The launch of the 'Grain-for-Green' Programme in the late 1990s resulted in restoration of pasture and became the primary reason of cultivated land loss. The total amount of cultivated land removed during 1997–2003 was 9.071 Mha, and the net loss was 6.647 Mha (5.1% of total cultivated land; [Yan \*et al.\* 2006](#)). This cancelled out increases due to land reclamation, consolidation and recultivation. Up to 2003, 5.740 Mha of cultivated land had been taken by the Grain-for-Green Programme which accounted for 63% of total cultivated land loss. The equivalent figures for agricultural, restructuring, construction and natural hazards were 1.5 Mha (16% of total loss), 1.3 Mha (15% of total loss) and 0.5 Mha (6% of total loss), respectively.



Table 2. Prediction of China's cultivated land in 2001–2050 (unit: Mha).

	year	2001–2010	2011–2020	2021–2030	2031–2040	2041–2050
sources of supplement	reclamation	2.026	1.877	1.137	0.557	0.267
	consolidation	1.784	1.233	1.143	1.053	1.328
	abandoned land recultivation	44.7	79.2	103.7	112.7	107.2
sources of loss	grain for green project	–14.667	—	—	—	—
	construction land	–2.023	–1.635	–0.948	–0.890	–0.741
	agricultural structure adjustment	–1.839	–0.904	—	—	—
	natural hazards	–0.648	–0.523	–0.460	–0.432	–0.423
change of cultivated land		–14.920	0.840	1.909	1.415	1.503
total cultivated land		113.313	114.153	116.062	117.477	118.980
per capita (ha)		0.083	0.079	0.079	0.081	0.085

Table 3. Prediction of food consumption *per capita* in China from 2010 to 2030 (unit: kg).

year	corn	legume	edible plant fat	vegetable	fruit	meat	dairy	egg	aquatic product
2010	152	13	10	149	40	29	18	15	17
2020	147	15	10	157	48	28	28	17	19
2030	146	20	10	162	53	28	41	17	19

### (b) Predicting China's cultivated land area for 2000–2050

Yan *et al.* (2006) used scenario and tendency analyses to predict agricultural restructuring, construction, natural hazards, land reclamation, consolidation and recultivation. The analysis was based on the sources of and driving forces for changes in cultivated land and the dynamics of China's population, economy and society. Changes in cultivated land for the period of 2000–2050 due to the Grain-for-Green Programme were also taken account of.

The results show that the first decade in twenty-first century will be a period with rapid loss of cultivated land (table 2). Cultivated land is predicted to decline dramatically from 128 to 113 Mha between 2001 and 2010, most of which can be attributed to the Grain-for-Green Programme. After 2010, there will be no cultivated land loss due to the Grain-for-Green Programme because by 2010, all the planned cultivated land with serious soil erosion would ultimately be restored to forestry or grassland. Annual loss of cultivated land for construction will still be over 0.1 Mha, but will be compensated for partially by land consolidation and recultivation of abandoned land. When China's population reaches its peak in 2030–2040, the total area of cultivated land will be around 117.5 Mha. By 2050, the total area of cultivated land will be 119 Mha, still 9.25 Mha less than that in 2000.

Cultivated land area *per capita*, during 2000–2010, will decline approximately 18%, from 0.101 to 0.083 ha; during 2020–2030, despite a slight increase of total cultivated land, cultivated land area *per capita* will still decline and reach the lowest point, 0.079 ha, due to the impacts of increasing population; during 2030–2050, as the population decreases, the *per capita* area will increase and reach 0.085 ha by 2050 (Yan *et al.* 2006).

## 5. ANALYSIS OF CHINA'S FOOD SECURITY IN 2000–2050

### (a) Future food demand

The *per capita* food demand and structure for 2000–2050 were predicted by referring to the Outline for the Development of Food and Nutrition in China (2000–2010) and Goals for the Development of Food in China during 2010–2030 (table 3). Food demand *per capita* of other Asian countries and regions (e.g. Japan, Taiwan, Hong Kong) with different levels of economic development but with a similar food structure was also referred to. Demand *per capita* for different kinds of food was converted into grain demand according to the grain conversion ratio for each. China's total grain demand was then calculated.

Table 4 shows the *per capita* and total demands for grain in 2000–2050. Both *per capita* and total demands for grain will continuously increase in the next five decades. The greatest total demand will take place during 2000–2020, from 513 to 648 Mt. The main reason is that this is the period during which China will develop into a wealthy society with improved food consumption structures and population increase. During 2020–2050, increase in the total demand for grain will slow down because the food consumption structure is predicted to become stable and population increase will dwindle. By 2050, the total demand for grain will be 700 Mt, 52 million greater than that in 2020.

### (b) Future food supply

The total yield of grain at 10-year intervals before 2050 was calculated by using the total sown area of grain crops and unit area grain yield. The sown area can be calculated from the data for cultivated land area, multiple cropping index (MCI) and proportion of the sown area of grain crops to that of farm crops. Thus, the total yield of grain of different periods in the future was

Table 4. Prediction of total and *per capita* grain demand in China in 2000–2050.

year	2000	2010	2020	2030	2040	2050
demand for grain <i>per capita</i> (kg)	400	420	450	465	480	500
total population (million)	1282.05	1369.88	1440.87	1460.57	1449.23	1400.23
total grain demand (Mt)	512.82	575.35	648.39	679.17	695.63	700.12

calculated as follows:

$$\text{total\_yield}_t = \text{area\_CL}_t \times \text{Pr op}_t \times \text{MCI}_t \times \text{yield}_t, \quad (5.1)$$

where  $\text{total\_yield}_t$  is the total yield of grain in Mt in year  $t$ ;  $\text{area\_CL}_t$  is the total cultivated land area in ha in year  $t$ ;  $\text{Pr op}_t$  is the proportion of the sown area of grain crops to that of farm crops in year  $t$ ;  $\text{MCI}_t$  is the multiple cropping index (MCI) in year  $t$ , and  $\text{yield}_t$  is the grain yield in Mt ha in year  $t$ .

Associated with socio-economic development, food consumption structure will be upgraded in the next two decades, the demand for vegetables, fruits, dairy and aquatic products will accordingly increase and the demand for grain will decrease. Thus, the proportion of the sown area growing grain crops will keep declining up to 2020, but the decline will slow down under the strengthening pressure from total grain demand. The proportion is predicted to be approximately 65% in 2010 and 62% in 2020; after 2020, the proportion will be stable or there may be a slight decrease (to around 58% in 2050) with the stabilization of food consumption structure. During the period 2020–2050, the proportion of the area growing grain crops will be impacted mainly by the alleviation of grain demand and the need to improve agricultural competitiveness.

When predicting grain yield per hectare and MCI, we analysed key factors of agricultural production, including irrigated land area, agricultural water-use, fertilizer and pesticide use, labour and machinery, agricultural sciences and technology and impacts of natural hazards.

MCI has improved gradually in the past 20 years. During 1985–1995, MCI increased from 1.48 to 1.58 (the theoretical maximum value of MCI is 1.9 in China). In coming decades, beneficial advances in agricultural technology and increases in agricultural input will result in the elevation of MCI. On the other hand, limited agricultural labour and decline of cultivated land quality will counter this. In addition, the historical experience of developed countries has indicated that both cultivated land and MCI decrease in the process of industrialization. Therefore, MCI in China will neither drop nor rise dramatically during 2020–2050 due to the combined effects of large population, reduction of cultivated land, increasing grain demand and a national policy of encouraging grain production.

China's grain yield per hectare has rapidly increased in the past decades. The grain yield per hectare during the period 1980–2000 was calculated and adjusted by reference to land survey data in 1996. The results show that China's grain yield per hectare increased by 62.6% (annually 2.5%), from 1997 kg ha<sup>-1</sup> in 1980 to 3246 kg ha<sup>-1</sup> in 2000. However, China's grain yields

per hectare increased by 23.8% (annually 2.2%) during the period 1986–1995, while only increasing 8.7% (annually 1.7%) between 1996 and 2000.

Grain yield per hectare depends on advancement of agricultural sciences and technology, construction of farm infrastructures, fertilizer use, planting structures for crops, water use, grain price and policy for agriculture production. Different input factors have different influences on agricultural production. Many researches have shown that earlier increases in China's grain yield per hectare were mainly a consequence of the increase in fertilizer use, mechanization and irrigation, while the contribution from the advancement of agricultural sciences and technology and labour inputs was relatively less significant (Chen 2001). It is reasonable to believe that the future grain yield will be benefit from investment in farm infrastructures, increase of irrigated area, increase of agricultural machine inputs and the advancement in agricultural sciences and technology, while the positive effect on the increase of grain yield per hectare from fertilizer use and labour inputs will gradually weaken. Based on the contribution of each agricultural production factor and the estimation of theoretical productivity per hectare, we predicted that the increasing trend of grain yield per hectare would gradually diminish. However, the potential increases in grain yield per hectare were still colossal. The annual grain yield per hectare could be expected to increase by approximately 2% during 2000–2010, 1–1.25% during 2010–2030 and 0.6–0.8% during 2030–2050 (Yan *et al.* 2006). Thus, grain yield per hectare, total yield of grain and output of grain *per capita* could be calculated (table 5). During 2000–2010, owing to the rapid decline in cultivated land area, the total yield of grain will only be 7 Mt higher than that in 2000. Total yield will only reach 470 Mt in 2010 in spite of the rapid increase in grain yield per hectare. It should be pointed out that the prediction of grain yield per hectare is conservative, because of the positive effect of the exclusion of the cultivation on poor soil resulting from the Grain-for-Green Programme was not considered in grain yield prediction. The total yield of grain is predicted to be 585 Mt in 2030 and 656 Mt in 2050, which is 116 Mt and 178 Mt more than that in 2010, respectively. The output of grain *per capita* will stand at around 360 kg during 2000–2030 and then reach 470 kg in 2050.

Because agricultural products obtained directly from cultivated land do not include aquatic products, seafood, flocks and herds, it is necessary to take account of productivity from other relevant agricultural resources to analyse the balance between food supply and demand. We adopted relevant research results by Chen (2001) and Wu & Li (2002) and adjusted those

Table 5. Prediction of grain yield in China from 2000 to 2050.

year	2000	2010	2020	2030	2040	2050
cultivated area (Mha)	128.23	113.31	114.15	116.06	117.48	118.98
yield of grain per hectare (kg)	3245.8	3956.6	4591.8	5072.2	5492.9	5831.5
multiple cropping index (MCI)	1.6	1.61	1.62	1.63	1.63	1.63
proportion of the sown area of grain crops to that of farm crops (%)	69.4	65	62	61	60	58
total yield of grain (Mt)	462.17	469.18	526.47	585.33	631.09	655.95
output of grain <i>per capita</i> (kg)	360	342	365	401	435	468

Table 6. Balance of total food demand and supply of China from 2000 to 2050.

year	2010	2020	2030	2040	2050
yield of grain from cultivated land (Mt)	469.18	526.47	585.33	631.09	655.95
yield of grain equivalents from other agricultural resources (Mt)	74.01	88.47	102.93	116.03	129.13
total agricultural yield (Mt)	543.19	614.95	688.27	747.12	785.08
total grain demand (Mt)	575.35	648.39	679.17	695.63	700.12
balance (Mt)	-32.16	-33.45	9.10	51.49	84.96
food self-sufficiency (%)	94.4	94.8	101.3	107.4	112.1

for consistency with our calculations. We predicted the productivity of grassland, pasture, ponds, woodlands and marine resources in the future, and converted the yield of meat, oil, dairy, eggs and aquatic products into the equivalent yield of grain (table 6). Total agricultural yield will be higher than 543 Mt in 2010, and gradually increase to 615 in 2020, 688 in 2030, 747 in 2040 and 785 in 2050.

### (c) *Future food security*

Based on the predictions of food demand and comprehensive food productivity from cultivated land and other agricultural resources, China's total agricultural productivity cannot be 100% self-efficient before 2020. The annual gap will be 30–35 Mt and China will need to import food to fill the gap. However, the food self-sufficiency ratio will be approximately 95%, which means that the situation of China's food security will be acceptable. After 2020, the gap between food supply and demand will dwindle until 2030 due to the reducing total grain demand. By approximately 2030, food self-sufficiency will reach 100%. By 2050, China will have surplus agricultural productivity of approximately 850 Mt. In conclusion, China could indeed meet its future demand for food when total productivity of agricultural resources is taken into account.

## 6. CHALLENGES IN CHINA'S SUSTAINABLE AGRICULTURAL DEVELOPMENT

Although China's food self-sufficiency is predicted to be acceptable in the next 50 years, agricultural sustainable development in China will still be challenged by water resource shortage, cultivated land decline, environmental pollution, faults in the mechanisms for protection of cultivated land and inefficiencies in the management of land tenure rights.

### (a) *Agricultural water use*

Agricultural water use for irrigation and animal husbandry plays an important role in agricultural production and is the main component in total water use in China. In 2000, the total agricultural water use in China was 378.3 billion m<sup>3</sup>, accounting for 68.83% of the overall national water use. We used quota estimation and scenario analysis to predict agricultural and other water demands in China during 2000–2050. The results show that the agricultural water demand will increase from 384.4 million m<sup>3</sup> (64.29% of all water use) in 2010 to 402 million m<sup>3</sup> (59.56% of all water use) in 2050. At the same time, the national overall water demand will reach 677 billion m<sup>3</sup> as its peak by 2040, which is close to the maximum of China's available water resource (the exploitable water resource of China is approximately 850–1100 billion m<sup>3</sup>; Li & He 2000). Thus there will be potential conflict between water demand and supply, and the competition for water will become more intense in the future. Undoubtedly, agricultural water use will continue to be less competitive because per unit water output value in agriculture is lower than that in industry.

In addition to scarce water resources in China, the efficiency of agricultural water use is relatively low. The average use coefficient of transportation pipe for irrigation is below 0.6, which means that nearly half of agricultural water is wasted during transportation and approximately 140 billion m<sup>3</sup> of water is lost annually. At present, 0.96 m<sup>3</sup> of water is required to yield 1 kg of grain in China, which is twofold of that in developed countries. For example, Israel needs only 0.43 m<sup>3</sup> of water to yield 1 kg of grain (Jiang 2001).

Water use efficiency can be improved in two ways:

- (i) Modify pipe systems to reduce unnecessary loss in transportation. More investments in agricultural infrastructures are needed.
- (ii) Technology and equipment for water saving need to be advanced. For example, current flood

irrigation can be transformed by small border irrigation or long border irrigation; sprinkler irrigation technology and equipment; drip irrigation; and micro-sprinkler irrigation technology (Wang & Jiang 1998).

### (b) *Cultivated land resources*

#### (i) *Driving forces for cultivated land loss in the future*

Land supply and demand and land-use mode are mainly decided by population, economy, society and natural conditions (Li *et al.* 2001). From the view point of the complex socio-economic-natural systems, the driving forces for China's cultivated land loss in the last decades included mainly its huge population with a trend of continuous growth, socio-economic development and environmental pressure (Yan *et al.* 2005).

The huge size of the population is the greatest challenge for China's sustainable development and is the prime reason for resource shortage and environmental degradation (Heilig 1999). Continuous population increase before 2030 will undoubtedly create increasing demand for cultivated land, grassland, forest and land for construction. The economic benefit derived from land use is the decisive parameter in the land resource distribution, and cultivated land is often considered to contribute a relatively low economic benefit (Brown 1995). Thus, the increasing demand for cultivated land can only be met by exploitation of marginal land. However, intensive expropriation of marginal land would cause environmental problems, such as soil erosion and land degradation, which threatens the sustainability of land use (Tian *et al.* 2003).

The experience of developed countries indicates that industrialization is always accompanied by cultivated land loss. The decrease in China's cultivated land seems normal under the process of industrialization. However, China's cultivated land is decreasing at an alarming speed, which threatens China's food security and sustainable agricultural development. Based on statistical data from CSSB, China's GDP has increased CNY 4880 billion during 1996–2003; over the same period, China has lost 6.65 Mha of cultivated land. This means that a CNY 1000 increase in GDP results in a 1.36 ha loss of cultivated land. Cultivated land loss due to industrialization is mainly a consequence of use for construction and urban expansion. Among the cultivated land loss during 1996–2003, approximately 1.33 Mha of cultivated land was taken for construction, accounting for 43.8% of the total cultivated land loss (excluding the loss for the Grain-for-Green Programme). Although urbanization has both positive and negative effects on cultivated land (Li & Liu 2003), a decrease in the average productivity of cultivated land is observed. Some studies have indicated that more than 0.2 ha of reclaimed land is required to make up for the loss of productivity from only 0.06 ha of cultivated land used for urban expansion (Yu & Hu 2003). The difference in quality between the lost cultivated land and reclaimed land which substitutes for it has lowered the overall quality of China's cultivated land. According to research from the Institute of Remote Sensing Applications, CAS, the centre of China's cultivated

land has moved north 28.34 km and the quality of cultivated land has decreased by 2.52% from 1985 to 1996 (Gao *et al.* 1998).

Land-use patterns are obviously influenced by policy. Previous inappropriate policies, such as 'grain production as agriculture core' (*yi liang wei gang*), caused environmental problems in China, although cultivated land was increased to implement the policy (Yan *et al.* 2006). China's government has recognized these problems and adjusted its agricultural policies to include environmental protection and ecological restoration. Several national programmes (e.g. the Natural Forest Protection Programme, the Desertification Combating Programme, the Grain-for-Green Programme) have been positively implemented since 1990s. Although these programmes, especially the Grain-for-Green Programme, cause a great deal of cultivated land loss, their benefits to the environment are vital to sustainable agricultural development in the long run.

More serious environmental degradation caused by inappropriate human activity has caused the shrinkage of cultivated land area and reduction in cultivated land quality, such as land degradation and soil erosion, desertification and salination.

#### (ii) *Protection mechanisms for cultivated land*

Effective protection of cultivated land is essential to ensure food security and sustainable agricultural development in China. The current protection mechanisms in China have two major problems:

- (i) land-use programming, in which the authority of relevant administrations cannot be effectively countered and there is no joint land-use and urban construction programming and
- (ii) protection of basic farmlands that focus only on the area of farmland in a protected area, but ignore the productivity of farmland resulting in declines in average productivity of cultivated land.

### (c) *Suggestions*

To overcome the restrictions in China's sustainable agricultural development, it is suggested that the following actions should be taken:

- (i) harmonization of different land-use patterns to meet demands of economic development and agricultural production,
- (ii) enhancement of ecological and environmental protection when supplementary land is brought into cultivation,
- (iii) design of a suitable land reclamation policy, and
- (iv) increase in capital investment for land consolidation and recultivation of abandoned land.

Furthermore, improving land use efficiency will also be effective in releasing the pressure on agricultural production due to the shortage of cultivated land. According to our estimation, accommodation capacity can be improved 40% if the plot ratio of the stock construction land is increased from 0.3 to 0.5.



Approximately 3.7 Mha of land will be saved if land for residential use in rural areas decreased to 120 m<sup>2</sup> *per capita* and 6 Mha of land will be saved if that decreased to 100 m<sup>2</sup> *per capita*. Thus, it is possible to meet the land demand for construction for a high population over the next 30 years.

#### (d) *Tenure mechanism of agricultural land*

In China, the basis of agricultural land tenure rights is the household responsibility system (HRS). Agricultural land is owned collectively, but use and management of the land are up to individual households. As the possessors of agricultural land, households can obtain direct and indirect benefit. Land provides a potential employment opportunity for peasants who have less chance to work in cities (Brandt *et al.* 2004) but, more importantly, access to agricultural land can help peasants avoid an uncertainty of food supply and income providing the necessary food guarantee and insurance (Tao & Xu 2005).

The HRS stimulated the Chinese peasants' enthusiasm for production and accelerated agricultural production during the 1980s (CSSB 2006). However, the positive effects on long-term improvement of agricultural productivity have gradually faded and negative effects are becoming more obvious. There are at least three problems associated with the HRS:

- (i) Agricultural land is divided into small pieces and each piece is supposed to be farmed by a single household. It was found that the average agricultural land area for each household was 9.3 mu (1 ha is equal to 15 mu) and was even subdivided into smaller pieces in the mid-1980s. The average area for a single household decreased to 8.47 mu and was further subdivided in 1990 (Zhao 2001). These fragmented areas of land can only support small-scale agricultural production and restrict the application of modern agricultural technology.
- (ii) Being identified as a peasant is a decisive factor in obtaining access to agricultural land. There is no economic compensation when the access is lost. Thus, peasants who have been engaged in non-agricultural activity are reluctant to give up their access rights and this results in a deficiency of investment in inefficient use of some farmland.
- (iii) Separating the ownership and access to agricultural land has, to some extent, made peasants focus primarily on short-term outputs from agricultural land, causing declines in land quality and harming land-use sustainability (Yu *et al.* 2003).

There are deficiencies existing in the current land expropriation policy. Farmland can be converted into construction land through expropriation but the expropriation process lacks careful planning and the compensation price is rather low (Guo 2001). This has encouraged governmental land rent and stimulated land sale (Zhang 2000). Moreover, there is no effective land market to create a reasonable price (Dowall 1993). Lack of an economic compensation system is an

important reason for inefficiency in cultivated land protection, resulting in breach of land use regulations and unreasonable occupation of cultivated land.

In order to solve these problems, the current land tenure rights system should be reformed and HRS should be improved. It is suggested that the following actions should be taken:

- (i) identify distinct land property and access rights, and define reasonable rights and responsibilities of possessors (collectively) and managers (peasants),
- (ii) strengthen land-use supervision on cultivated land by collective and government action,
- (iii) improve transfer mechanisms for land-use rights, and form multiform distributions of land-use rights that accord with the rules of the market economy,
- (iv) establish market distribution mechanisms for farmland (Zhang 2000), and accelerate the introduction of price mechanisms that are suitable for a land market,
- (v) establish and improve the tax system of compensation for land use and reclamation for new construction land, and enhance the effects of economic measures, such as land price and land tax, on land-use adjustment and control, and
- (vi) establish economic compensation mechanisms for cultivated land protection, and adjust benefit participation mechanisms to solve problems of externalities and unmatched cost profit in cultivated land protection.

#### (e) *Use of fertilizers and pesticides*

In 2005, 47.66 Mt of fertilizers were used in China, including 22.29 Mt of nitrogenous fertilizer, 7.44 Mt of phosphate fertilizer and 4.90 Mt of potash fertilizer (CSSB 2006). However, the contribution of fertilizers to yield in China is still low. The average contribution made by fertilizers to grain yield is only 46.43%, and that is increased approximately 8.84 tonnes a per tonne of fertilizer used (Peng 2000). Based on this contribution to yield, fertilizer consumption will be increased by at least 10.22–11.08 Mt to support a 100 Mt increase in grain yield during the twenty-first century.

China's average fertilizer consumption on cultivated land is 356.7 kg per ha, which is twofold of the maximum amount of fertilizer consumption in developed countries; nitrogenous fertilizer consumption on cultivated land is 170.9 kg ha<sup>-1</sup>, 2.5 times higher than the world average; phosphate fertilizer is 56.6 kg ha<sup>-1</sup>, 1.86 times higher than the world average. These numbers imply that fertilizers are being overused in China. On the other hand, the efficiency use of fertilizer is rather low. According to an investigation by China's Ministry of Agriculture, nutrient-use efficiency of fertilizer is only 30–40%, only a half of that (60–70%) in developed countries. Over-consumption and low efficiency of fertilizer cause large amount of unabsorbed fertilizers remaining in soil leading to a series of environmental problems. The China Council for International Cooperation on

Environment & Development (2004) reported that approximately 1.23 Mt of nitrogen are discharged annually into rivers and lakes, 494 000 tonnes into underground water and 2.99 Mt into the atmosphere. Approximately 60% of the annual use of fertilizer N in the Yangtze River area is lost from gaseous and agricultural non-point sources (Shen *et al.* 2001).

China has the largest pesticide consumption in the world. The total amount of pesticide consumption increased to 1.33 Mt in 2003 from 862 000 tonnes in 1983. In common with the problems of fertilizer use, abuse and low efficiency of pesticide use are also common. According to the Chinese Academy of Agricultural Sciences (Zhang *et al.* 2004), 40% of pesticide used in rice production and 50% in cotton production are superfluous. Another problem with pesticide use is the high proportion of high-noxious pesticide in agriculture. The use of methamidophos, dimethoate, parathion, methylparathion and dichlorophos was frequent and accounted for 90800 tonnes in 1990 (Zhong *et al.* 2000).

Pollution caused by careless and over use of pesticides and fertilizers has become more serious in agricultural environmental systems. According to the statistics of 23 provinces in China, there were 891 agricultural pollution events in 2000, 40 000 ha agricultural land was polluted and 25 000 tonnes of agricultural product were lost resulting in CNY 220 million of direct losses (SEPA 2001). Moreover, the deficiency of organic fertilizer use has resulted in a decrease in soil organic matter, unbalanced soil nutrition and a decrease in fertility (Ma & He 2002). Organic matter content in China's cultivated land has decreased to 1.5%, much lower than that in North America (2.5–4.0%) and Canada (3.0–4.5%); organic matter content of black soil in northeast China has declined from 8–10% to 1–5% (Liu 2002).

It is necessary to take effective measures to control fertilizer and pesticide abuse and improve efficiency in fertilizer and pesticide use to achieve more sustainable agricultural production and agroecosystems. We suggest the following actions:

- (i) standardize pesticide and train peasants to use relevant technology correctly,
- (ii) improve the existing production techniques and strengthen research and development on new fertilizers and safe pesticides, and
- (iii) improve cultivation technology to eliminate the overuses of fertilizers and pesticides.

#### (f) *Ecological agriculture in China*

The combination of modern scientific, technological and traditional agriculture in China presents a new opportunity, eco-agriculture. This requires the application of ecological theory and methods of systems science. More than one-sixth of counties throughout China have been selected to carry out an eco-agricultural county project. The area of the eco-agriculture project is more than 6.67 Mha, accounting for 6% of the total cultivated land in China. During the process of China's eco-agricultural development during previous decades, primary theory, technology and model agricultural methods

characteristic for China have been developed. The introduction of eco-agriculture has greatly contributed to sustainable agricultural development (Li 2001). As an effective tool and general approach to sustainable agricultural development, eco-agriculture has been widely recognized in China.

However, the development and application of eco-agriculture are not without problems:

- (i) The lack of sufficient research on eco-agricultural theory and methods. Technological innovation, introduction and application of high technologies in eco-agriculture are slow and do not support the expansion of eco-agriculture.
- (ii) A low level of industrialization in eco-agriculture. At present, China's eco-agriculture is solely a production system that focuses on agricultural production and neglects the relationship between production and the market. Furthermore, the characteristics of China's agricultural production prevent the industrialization of eco-agriculture. These include: more population with less cultivated land; a shortage of agricultural input; and the HRS system.
- (iii) Inefficient measures for popularizing eco-agriculture. Although economic, social, and ecological benefits have been obtained in the eco-agricultural regions, effective technologies and modes of eco-agriculture have not been effectively popularized more widely and benefits of eco-agriculture to environmental protection are limited.

To develop eco-agriculture in China will require the following measures:

- (i) Strengthening research in the field of eco-agricultural theory and technology. This research should focus on: 1 agricultural ecological system theory, 2 application of resource scarcity theory, externality theory and methods to eco-agriculture, 3 introduction and application of high technology such as genomic technology, information technology and other technologies, 4 assessment of the impact of modern techniques on ecosystems and protection measures from negative effects, and 5 advancement in the design of the ecological engineering model.
- (ii) Establishing advanced eco-agricultural engineering models based on current models and application conditions. It is also convenient and effective to optimize traditional technology for ecological benefit.
- (iii) Seeking a model for eco-agricultural industrialization that fits local conditions. Zhou *et al.* (2004) proposed three practical ways: the comprehensive development way through optimization grouping or regrouping, the economic way according to marketing direction and the protective way according to limit of resources.

- (iv) Popularizing eco-agriculture through information service and financial support. More technology information service and financial support need to be provided to households to promote the conversion from the traditional production model to the eco-agricultural model.

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